Astronomy & Astrophysics manuscript no. metal-arxiv
October 9, 2009

On the influence of high energy electron populations on metal abundance estimates in galaxy groups and clusters.

D. A. Prokhorov[1,2]

[1] Institut d'Astrophysique de Paris, CNRS, UMR 7095, Université Pierre et Marie Curie, 98bis Bd Arago, F-75014 Paris, France
[2] Moscow Institute of Physics and Technology, Institutskii lane, 141700 Moscow Region, Dolgoprudnii, Russia

Accepted . Received ; Draft printed: October 9, 2009

ABSTRACT

Aims. Spectral line emissivities have usually been calculated for a Maxwellian electron distribution. But many theoretical works on galaxy groups and clusters and on the solar corona suggest to consider modified Maxwellian electron distribution functions to fit observed X-ray spectra. Here we examine the influence of high energy electron populations on measurements of metal abundances.
Methods. A generalized approach which was proposed in the paper by Prokhorov et al. (2009) is used to calculate the line emissivities for a modified Maxwellian distribution. We study metal abundances in galaxy groups and clusters where hard X-ray excess emission was observed.
Results. We found that for modified Maxwellian distributions the argon abundance decreases for the HCG 62 group, the iron abundance decreases for the Centaurus cluster and the oxygen abundance decreases for the solar corona with respect to the case of a Maxwellian distribution. Therefore, metal abundance measurements are a promising tool to test the presence of high energy electron populations.

Key words. Galaxies: clusters: general; Atomic processes; Radiation mechanisms: non-thermal

1. Introduction

Galaxy clusters are large structures in the Universe, with radii of the order of a megaparsec. Groups of galaxies are the poorest class of galaxy clusters. The space between galaxies in clusters is filled with low-density $\sim 10^{-3}$ cm^{-3} high temperature ($k_{\rm B}T \sim 1-10$ keV) gas (for a review, e.g. Sarazin 1986). The temperatures of 1-10 keV are close to the values of the K-shell ionization potentials ($I_{\rm Z} = Z^2 Ry$, where Z is the atomic number and Ry is the Rydberg constant) of heavy elements with atomic numbers in the range of Z=10-26.

Emission lines from heavy elements were detected by X-ray telescopes from galaxy groups and clusters. The current instruments (XMM-Newton, Chandra and Suzaku) have provided precise measurements of the chemical abundances of many elements (O, Ne, Mg, Si, C, Ar, Ca, Fe and Ni) in groups and clusters. Metal abundances around 0.5 in Solar units of Anders & Grevesse (1989) are derived under the assumptions of collisional equilibrium (for a review, see Werner et al. 2008).

The ionization rates, recombination rates and emissivity in a spectral line have usually been calculated for a Maxwellian electron distribution (e.g. Mewe & Gronenschild 1981). However, in many low-density astrophysical plasmas, the electron distribution may differ from a Maxwellian distribution (e.g. Porquet et al. 2001).

Hard X-ray tails reported from BeppoSAX observations in the X-ray spectra of some galaxy clusters (Fusco-Femiano et al. 1999; Fusco-Femiano et al. 2004; Rossetti & Molendi 2004 for the Coma cluster; Kaastra et al. 1999 for the Abell 2199; Molendi et al. 2002 for the Centaurus cluster) were interpreted as bremsstrahlung emission from non-thermal subrelativistic electrons (see e.g. Sarazin & Kempner 2000) or from thermal electrons with a Maxwellian spectrum distorted by a particle acceleration mechanism (Blasi 2000; Liang et al. 2002, Dogiel et al. 2007). The bremsstrahlung interpretation is associated with a huge energy output of emitting particles and faces energetics problems (e.g. Petrosian 2001). Evidence for a hard X-ray excess above the thermal emission was also discovered in galaxy groups with ASCA (Fukazawa et al. 2001, Nakazawa et al. 2007). The evidence for and the nature of hard X-ray spectral tails in these galaxy groups and clusters are discussed in the review by Rephaeli et al. (2008).

The use of non-extensive thermo-statistics (Tsallis 1988; for a review, see Tsallis 1999), based on the natural generalization of entropy for systems with long-range interactions, was proposed by Hansen (2005) to fit the X-ray spectrum observed near NGC 4874 (near the center of the Coma cluster). We consider non-extensive thermo-statistics as another approach to explain hard X-ray excess in groups and clusters in the framework of the bremsstrahlung model.

A more traditional interpretation of hard X-ray tails based on the inverse Compton scattering (ICS) of relativistic electrons on relic photons (Sarazin & Lieu 1998) faces a serious problem. The combination of hard X-ray and radio observations within the ICS model implies a magnetic field much lower than the values derived from Faraday rotation measurements (e.g. Clarke et al. 2001). Yet several arguments have been proposed to alleviate (at least in part) the disagreement (for a review, see Brunetti 2003; Ferrari et al. 2008; Petrosian et al. 2008).

The presence of high energy subrelativistic electrons (non-thermal subrelativistic electrons or thermal electrons with a Maxwellian spectrum distorted by the particle acceleration mechanism) or the use of non-extensive thermo-statistics must be probed using various observational methods in order to test interpretations of X-ray tails from galaxy clusters.

Send offprint requests to: D.A. Prokhorov e-mail: `prokhoro@iap.fr`

The Sunyaev-Zel'dovich (SZ) effect can be used to constrain the electron distribution in galaxy clusters. The study of the influence of high energy subrelativistic electrons on the SZ effect was done for the Coma and Abell 2199 clusters by Blasi et al. (2000) and Shimon & Rephaeli (2002). A method based on the measurement of the spectral slope around the crossover frequency of the SZ effect was proposed by Colafrancesco et al. (2009) to analyse the high energy electron populations in galaxy clusters.

A new probe to study the electron distribution in galaxy clusters, namely the flux ratio of the emission lines due to FeKα transitions (FeXXV and FeXXVI) was considered by Prokhorov et al. (2009). This flux ratio is very sensitive to the population of electrons with energies higher than the ionization potential of a FeXXV ion (which is $\approx$ 8.8 keV). The influence of the high energy subrelativistic electron population on the flux ratio is more prominent in low temperature clusters (as Abell 2199) than in high temperature clusters (as Coma), because the fraction of thermal electrons with energies higher than the helium-like iron ionization potential in low temperature clusters is smaller than that in high temperature clusters. However, the FeXXVI line is weak in low temperature clusters and current instruments do not have sufficient sensitivity to measure the iron line flux ratio.

Kaastra et al. (2009) have shown that relative intensities of the satellite lines are sensitive to the presence of supra-thermal electrons in galaxy clusters and that the instruments on future missions like Astro-H and IXO will be able to demonstrate the presence or absence of these supra-thermal electrons.

In this paper we study the influence of high energy electron populations on metal abundance estimates in galaxy groups and clusters and show that the effect of high energy particles can be significant. This effect is a promising test to the presence of high energy subrelativitic electrons in galaxy groups and clusters because of substantial changes in abundance estimates for modified Maxwellian distributions. We also consider the effect of high energy electrons on abundance estimates in the solar corona where the presence of modified Maxwellian electron distributions has been proposed.

The paper is organized as follows. In Sect. 2.1 we choose a galaxy group and a galaxy cluster where high energy subrelativistic electron populations have been proposed and derive values of the electron distribution parameters. We calculate the changes in metal abundances with respect to the values for a Maxwellian distribution in Sect. 2.2. We discuss the bremsstrahlung model of hard X-ray emission from galaxy clusters in Sect. 3 and present our conclusions in Sect. 4. We calculate an oxygen abundance drop for the solar corona in Appendix A.

2. Metal abundances in groups and clusters with a high energy electron population.

Usually metal abundances are derived under the assumption of a Maxwellian electron distribution. Let us consider here the influence of high energy subrelativistic electron populations on metal abundance determinations.

2.1. High energy subrelativistic electron populations in galaxy groups and clusters.

Since we want to analyse the influence of a high energy subrelativistic electron population on abundance estimates of chemical elements with atomic numbers Z⩽26, we must consider cool clusters where the influence of high energy subrelativistic electrons on impact excitation and ionization is more important.

The two objects which will be considered below are the HCG 62 group and the Centaurus cluster, with respective temperatures of 1 keV and 3.5 keV. These objects are interesting because of hard X-ray excess detections by Fukazawa et al. (2001) and Molendi et al. (2002), suggesting a possible high energy subrelativistic electron component if these hard X-ray excesses are interpreted via bremsstrahlung emission.

The HCG 62 group is a bright group of galaxies at a redshift z=0.0146. The best fit temperature is kT=0.95 ± 0.03 keV in the energy band below 2.5 keV (Nakazawa et al. 2007). A hard X-ray excess from this galaxy group was discovered by Fukazawa et al. (2001). The highly significant hard X-ray signal in the energy band 4.0-8.0 keV, of which only $\sim$ 25% can be accounted for by thermal IGM (intragalactic medium) emission, was reconfirmed by Nakazawa et al. (2007). Abundances of Mg, Si, S and Fe were obtained with Suzaku by Tokoi et al. (2008).

The Centaurus cluster (Abell 3526) is amongst the nearest (z=0.0114) and brightest clusters in the X-ray sky. Its average gas temperature is kT=3.6 ± 0.1 keV (Molendi et al. 2002). Molendi et al. (2002) detected a hard X-ray excess at the 3.6σ level and concluded that it is impossible from the Beppo-SAX PDS data alone to establish the origin of this emission. The abundances of chemical elements in the Centaurus cluster were studied by Molendi et al. (2002) and Fabian et al. (2005).

To interpret hard X-ray spectral tails in the framework of the bremsstrahlung model, different electron distributions were proposed (e.g. Dogiel 2000; Sarazin & Kempner 2000; Dogiel et al. 2007). In the paper by Sarazin & Kempner (2000) it is assumed that the supra-thermal electron populations start at an electron kinetic energy 3kT, where T is the temperature of the intracluster medium (ICM). This electron distribution was considered by Shimon & Rephaeli (2002) for an analysis of the influence of supra-thermal electrons on the SZ effect and by Prokhorov et al. (2009) for an analysis of electron distributions by means of the flux ratio of iron lines FeXXV and FeXXVI. In this case the electron distribution function is given by:

$$\begin{aligned} f_1(x) &= f_{\mathrm{M}}(x), \quad x < 3 \\ f_1(x) &= f_{\mathrm{M}}(x) + \lambda x^{-(\mu+1)/2}, \quad x \geq 3 \end{aligned} \tag{1}$$

where x=E/kT, $f_{\mathrm{M}}(x)$ is a Maxwellian function, $\mu = 3.33$ is taken from Sarazin & Kempner (2000) and the normalization coefficient λ is calculated from observational data. For the calculations of the ionization, excitation and recombination rates the electrons with very high energies (≥20 kT) have negligible effect (Porquet et al. 2001), therefore we can place the cut-off at any energy above that of 20 kT without changing line emissivities.

Another approach to fit the X-ray spectra of galaxy clusters in the framework of the bremsstrahlung model was proposed by Hansen (2005). He considered the ICM in thermodynamical equilibrium, but with an electron distribution function which is defined through non-extensive thermo-statistics (Tsallis 1988). Reasons for using Tsallis statistics in galaxy clusters are discussed in Sect. 4 of Hansen (2005). The equilibrium distribution function in non-extensive thermo-statistics (e.g. Silva et al. 1998) is:

$$f_2(x) = C\,\sqrt{x}\,(1-(q-1)x)^{1/(q-1)} \tag{2}$$

where C is the normalization constant, and q is the parameter quantifying the degree of non-extensivity.

The electron distribution $f_2(x)$ has the same form as a Kappa-distribution which is frequently interpreted as a consequence of acceleration mechanisms in the solar corona (Leubner 2004).

Let us find values of the distribution parameters λ (see Eq. 1) and q (see Eq. 2) from the ASCA data for the HCG 62 group and from the Beppo-SAX data for the Centaurus cluster:

1. The HCG 62 group. Fukazawa et al. (2001) using the observed luminosity ratio of the non-thermal and thermal X-ray continuum components, and the non-thermal bremsstrahlung model (Kempner & Sarazin 2000) estimated that the non-thermal electron population is 6% of the thermal electron population (the non-thermal electron energy density is 25% of the thermal electron energy density). We obtain the values of $\lambda = 0.28$ and $q = 0.97$ by integrating over the electron spectra $f_1(x)$ and $f_2(x)$ respectively.
2. The Centaurus cluster. The total luminosity of the non-thermal component in the 20-200 keV band was calculated by Molendi et al. (2002) from a Beppo-SAX observation. Molendi et al. (2002) considered the bremsstrahlung model as one of the possibilities to explain the hard X-ray excess. The luminosity in the 2-10 keV band was calculated by Fabian et al. (2005). From the observational data we derive that the non-thermal electron population is 5% of the thermal electron population (the non-thermal electron energy density is 21% of the thermal electron energy density) and obtain the values of $\lambda = 0.25$ and $q = 0.975$ by integrating over the electron spectra $f_1(x)$ and $f_2(x)$ respectively.

Note that supra-thermal electron populations that are 4% and 8% of the thermal electrons were also proposed by Sarazin & Kempner (2000) for the Coma and Abell 2199 clusters.

Evidence for non-thermal X-rays in galaxy clusters is still controversial (e.g. Rossetti & Molendi 2004; Kitaguchi et al. 2007). The Suzaku observation of the Coma cluster does not provide evidence for non-thermal excess in the central region of the Coma cluster (Wik et al. 2009). An analysis of Suzaku XIS and HXD measurements of HCG 62 resulted in an upper limit on non-thermal emission (Tokoi et al. 2008), but at a level which does not exclude the ASCA result.

The influence of the derived high subrelativistic electron populations on the metal abundance estimates will be considered in Sect. 2.2.

2.2. The influence of high energy electron populations on metal abundance estimates.

We now show that the effect of high energy subrelativistic electrons on hydrogen-like and helium-like emission lines can be significant. A generalized approach to calculate the emissivity in hydrogen-like and helium-like spectral (iron) lines for a modified Maxwellian electron distribution was given by Prokhorov et al. (2009). In this section we propose to study the sum of the H-like and He-like line volume emissivities (in units of photons $\mathrm{cm}^{-3}\ \mathrm{s}^{-1}$) instead of the line volume emissivity ratio.

The sum of the H-like and He-like line volume emissivities for a chemical element of atomic number Z can be written as

$$\varepsilon_Z = n_e n_H A_Z \times (\xi_{Z-2} Q_{Z-2} + \xi_{Z-1} Q_{Z-1} + \xi_{Z-1} \alpha_{Z-2} + \xi_Z \alpha_{Z-1}) \quad (3)$$

where n_e is the electron number density, n_H is the H ionic number density, A_Z is the abundance of the considered chemical element, ξ_{Z-2} and ξ_{Z-1} are the ionic fractions of He-like and H-like ions respectively, Q_{Z-2} and Q_{Z-1} are the impact excitation rate coefficients, and α_{Z-2} and α_{Z-1} are the rate coefficients for the contribution from radiative recombination to the spectral lines: He-like triplet and H-like doublet.

Let U denote the reduced expression for the sum of emissivities ε_Z defined as:

$$U = \frac{\xi_{Z-2} Q_{Z-2} + \xi_{Z-1} Q_{Z-1} + \xi_{Z-1} \alpha_{Z-2} + \xi_Z \alpha_{Z-1}}{\Gamma} \quad (4)$$

where $\Gamma = Z^{-4} \pi a_0^2 \sqrt{I_Z/m_e}$ corresponds to the characteristic rate coefficient value, m_e is the electron mass, a_0 is the Bohr radius, and I_Z is the K-shell ionization potential.

For the sake of clarity, we consider in more detail the electron distribution $f_1(x)$ because of the distinct non-thermal power-law component at $x \geq 3$. In this case the non-thermal electrons have energies higher than 3kT, which corresponds to the energies $E_{HCG62} = 3$ keV and $E_{A3526} = 10.5$ keV for the HCG 62 group and the Centaurus cluster (Abell 3526). Ionic fractions are very sensitive to the electron population with energies higher than the K-shell potential I_Z, therefore ions of argon $I_{Z=18} = 4.4$ keV and iron $I_{Z=26} = 9.2$ keV are promising for our analysis of electron distributions in the HCG 62 group and in the Centaurus cluster respectively.

In the analysis of the reduced emissivity U we use the method which was proposed by Prokhorov et al. (2009) to take into account the influence of the high energy subrelativistic electron population on the He-like and H-like line emissivities. All the necessary coefficients to calculate the direct ionization cross sections are taken from Arnaud & Rothenflug (1985), the radiative recombination rates are taken from Verner & Ferland (1996), and the dielectronic recombination rates are taken from Mazzotta et al. (1998). Note that the fraction of Li-like ions of Ar at temperatures kT≥1 keV is less than 5% and the fraction of Li-like ions of Fe at temperatures kT≥3.5 keV is less than 12% (e.g. Mazzotta et al. 1998). We have included the Li-like ion fractions in the analysis of the ionization balance.

In Fig. 1 we compare the reduced argon emissivity for the Maxwellian electron distribution and for the modified Maxwellian electron distribution $f_1(x)$, with a fraction of high energy subrelativistic electrons equal to 6% as in the HCG 62 group.

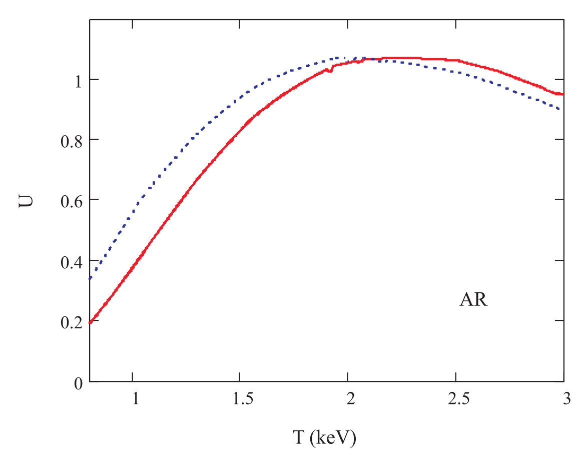

Fig. 1. Reduced argon emissivity U for a Maxwellian electron distribution (solid line) and for a modified Maxwellian distribution $f_1(x)$ (dashed line) for the HCG 62 group.

For the HCG 62 group (kT=1 keV) the reduced emissivity U for a modified Maxwellian distribution $f_1(x)$ increases by ≈ 49%

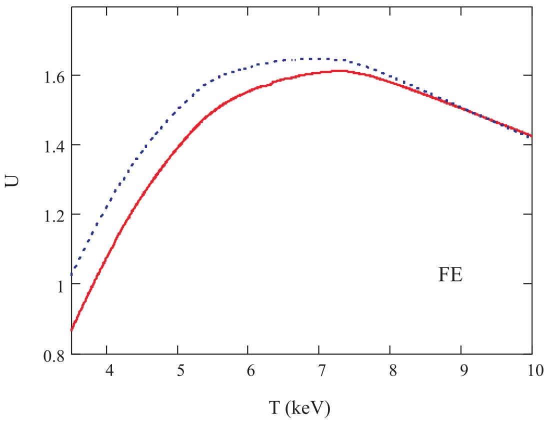

Fig. 2. Reduced iron emissivity U for a Maxwellian electron distribution (solid line) and for a modified Maxwellian distribution $f_1(x)$ (dashed line) for the Centaurus cluster.

with respect to the case of a Maxwellian distribution. Such an increase of the reduced emissivity U corresponds to a decrease of the argon abundance $A_{Z=18}$ for a constant value of $\varepsilon_{Z=18}$ (see Eq. 3). For a modified Maxwellian distribution $f_1(x)$ the argon abundance decreases by $\approx$ 33% with respect to the case of a Maxwellian distribution. The decrement of the argon abundance for a modified Maxwellian distribution $f_2(x)$ is 27%.

Abundances of Mg, Si, S and Fe in the HCG 62 group were calculated from Suzaku data by Tokoi et al. (2008), but the expected Ar abundance is 4.5 times smaller than the S abundance (Anders & Grevesse 1989) and it is more difficult to detect Ar lines. The predicted Ar abundance decrease is a tool to test the bremsstrahlung interpretation of the hard X-ray tail in HCG 62.

The Centaurus cluster is another interesting object to study. In Fig. 2 we compare the reduced iron emissivity for a Maxwellian electron distribution and for a modified Maxwellian electron distribution $f_1(x)$ with a fraction of high energy subrelativistic electrons equal to 5%, as in the Centaurus cluster.

We found that the iron abundance for the modified Maxwellian distributions $f_1(x)$ and $f_2(x)$ decreases by $\approx$ 15% and $\approx$ 13% respectively with respect to the case of a Maxwellian distribution.

We also calculated changes in the abundance estimates for the chemical elements closest in atomic numbers to Ar and Fe and found that: 1) for HCG 62, the Si abundance increases by 3%, and the S abundance decreases by 14%; 2) for the Centaurus cluster, the Ar abundance increases by 2%, and the Ca abundance increases by 0.5%.

High energy subrelativistic electrons lead to a higher apparent temperature. If the gas temperature is smaller than the temperature at which the reduced emissivity U of the chemical element has a maximum value, then the abundance estimate decreases because of an increase of the reduced emissivity with the temperature at these temperatures. However, if the gas temperature is higher than the temperature at which the reduced emissivity U of the chemical element has its maximum value, then the abundance estimate increases.

We now demonstrate how the argon and iron abundances inferred from X-ray observations yield important constraints on the fraction of high energy electrons. For this purpose, synthetic clusters with temperatures of 1 and 3.5 keV (as in the HCG 62 group and in the Centaurus cluster) and an electron distribution function $f_1(x)$ are considered. The dependences of both argon and iron abundance ratios for a modified Maxwellian distribution and for a Maxwellian distribution on the fraction of high energy subrelativistic electrons are shown in Fig. 3.

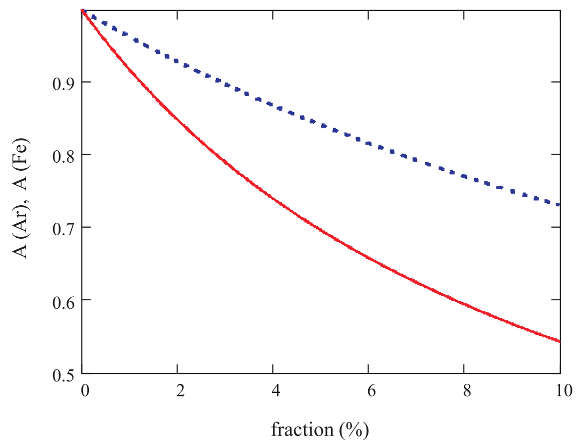

Fig. 3. The solid (dashed) line shows dependence of the ratio of the argon (iron) abundances for a modified Maxwellian distribution and for a Maxwellian distribution on the fraction of high energy electrons.

We conclude that high energy electron populations can affect derived metal abundances for the HCG 62 group and the Centaurus cluster.

3. Discussion

It can be supposed that, in addition to the bremsstrahlung-emitting thermal ICM and synchrotron-emitting, relativistic, non-thermal electrons, a high energy subrelativistic population of electrons exists which emits the hard X-ray excess as bremsstrahlung.

There are three possible origins for high energy subrelativistic populations: non-thermal (Sarazin & Kempner 2000), quasi-thermal (Blasi 2000; Dogiel 2000; Liang et al. 2002; Dogiel et al. 2007; Wolfe & Melia 2008), and thermal in the framework of the non-extensive thermo-statistics (Hansen 2005). Since line emissivities depend on the fraction of high energy electrons (e.g. Prokhorov et al. 2009) and do not depend on the origin of these electrons, we can use the electron distribution $f_1(x)$ to calculate line emissivities in the cases of the non-thermal and quasi-thermal electron origins.

Petrosian (2001) estimated the yield in non-thermal bremsstrahlung photons $Y \sim (dE/dt)_{\rm br}/(dE/dt)_{\rm c} \sim 10^{-5}$. Here $(dE/dt)_{\rm br}/(dE/dt)_{\rm c}$ is the ratio of bremsstrahlung to Coulomb losses of non-thermal electrons. Then for a hard X-ray flux $F_{\rm x} \sim 10^{43}$ erg/s a large amount of energy of the non-thermal electrons $F_{\rm e} \sim F_{\rm x}/Y \sim 10^{48}$ erg/s is transmitted to the background plasma. As a result the ICM should be heated above its observable temperature in less than 10 Myr (Petrosian 2001, Wolfe & Melia 2006).

It was, however, shown by Liang et al. (2002) and Dogiel et al. (2007) that a quasi-thermal electron population might overcome this difficulty via a higher radiative efficiency (and therefore a longer overheating time, but see Petrosian & East 2008). The energy supply necessary to produce the observed hard X-ray flux by quasi-thermal electrons is at least one or two orders

of magnitude smaller (Dogiel et al. 2007) than derived form the assumption of non-thermal origin of emitting electrons. Wolfe & Melia (2008) have also considered a quasi-thermal electron distribution to fit hard X-ray emission, but rather than requiring a second-order Fermi acceleration to produce the quasi-thermal electrons, they assumed quasi-thermal electrons are produced via collisions with non-thermal protons.

4. Conclusions

We have shown in this paper that the metal abundance estimates depend on the presence of high energy subrelativistic electrons proposed to account for measurements of hard X-ray excess emission from galaxy groups and clusters. Due to the impact of these energetic electron populations, the Ar abundance estimate in the HCG 62 group and the Fe abundance estimate in the Centaurus cluster significantly decrease by $\approx$ 30 and $\approx$ 15%, respectively.

These decreases in the Ar and Fe abundance estimates are determined by the high energy subrelativistic electron fractions (6% for the HCG 62 group and 5% for the Centaurus cluster) which are comparable to the thermal electron fractions with energies higher than the K-shell ionization potentials of Ar and Fe, respectively.

The influence of the high energy subrelativistic electron populations on the abundance estimates is measurable with current instruments. Therefore this probe is more efficient for detecting the high energy subrelativistic electron populations than that based on the Doppler broadening of the spectral lines proposed by Hansen (2005), which requires very high energy resolution, or than that based on the flux ratio of the emission lines (Prokhorov et al. 2009), which requires higher sensitivity instruments.

Other possibilities to produce the change in the metal abundance estimates in galaxy clusters are the effect of resonant scattering (Gilfanov et al. 1987) and the presence of multiphase hot gas - two temperature model (Buote & Fabian 1998, Buote 2000).

The effect of resonant scattering causes the decrement of the FeXXV line at 6.7 keV, and, therefore, the decrement of the flux ratio of the iron lines FeXXV/FeXXVI. A decrement of the Fe abundance is then produced, as in the case of a high energy subrelativistic electron population. To separate the effects of resonant scattering and the high energy subrelativistic population influence, the SZ effect from a high energy subrelativistic population can be analyzed. Following the method of Colafrancesco et al. (2009), we calculated the value of the slope of the SZ effect in the Centaurus cluster. We obtained the value of the slope $S \approx 0.033$ for both electron distributions $f_1(x)$ and $f_2(x)$ and the value of the slope $S \approx 0.028$ for a Maxwellian spectrum. Since the slope is equal to $S \approx 4.25 \times kT/(m_e c^2)$ for a Maxwellian electron spectrum without a high energy subrelativistic electron population (Colafrancesco et al. 2009), the value of the slope of $S = 0.033$ corresponds to that at an effective temperature $kT = 4.5$ keV, which is higher than the temperature $kT = 3.5$ keV observed with Beppo-SAX.

Buote (2000) analyzed the ASCA data for the HCG 62 group, the same data as analyzed by Nakazawa et al. (2007), and fitted the spectrum in the frame of a two-temperature model with temperatures $kT_1 = 0.7$ keV and $kT_2 = 1.4$ keV. Nakazawa et al. (2007) showed that the spectrum of the HCG 62 group is well reproduced by the two-temperature model of Buote (2000) in the energy range below $\sim$ 4 keV, but a fit of the full spectrum requires a thermal component with an unrealistically high temperature of $\sim$ 17.5 keV.

We have shown that high energy electron populations can affect derived metal abundances in galaxy groups and clusters and in the solar corona. Therefore, metal abundances are a promising tool for an analysis of the high energy subrelativistic electron component.

Acknowledgements. I am grateful to Florence Durret, Joseph Silk, William Forman, Vladimir Dogiel and Eugene Churazov for valuable suggestions and discussions and thank the referee for very useful comments.

References

Anders, E., Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197
Arnaud, M., Rothenflug, R. 1985, A&ASS, 60, 425
Blasi, P. 2000, ApJL, 532, L9
Blasi, P., Olinto, A. V., Stebbins, A. 2000, ApJ, 535, L71
Brunetti, G. 2003, in Matter and Energy in Clusters of Galaxies, ASP Conference Proceedings, 301, 349
Buote, D. A., Fabian, A. C. 1998, MNRAS, 296, 977
Buote, D. A. 2000, MNRAS, 311, 176
Clarke, T. E., Kronberg, P. P., Böhringer, H. 2001, ApJ, 547, L111
Colafrancesco, S., Prokhorov, D. A., Dogiel, V. A. 2009, A&A, 494, 1
Dogiel, V. A. 2000, A&A, 357, 66
Dogiel, V. A., Colafrancesco, S., Ko, C. M. et al. 2007, 461, 433
Dzifcakova, E., Kulinova, A. 2001, Solar Physics, 203, 53
Dzifcakova, E., Kulinova, A. 2003, Solar Physics, 218, 41
Fabian, A. C., Sanders, J. S., Taylor, G. B., Allen, S. W. 2005, MNRAS, 360, 20
Ferrari, C., Govoni, F., Schindler, S. et al. 2008, SSRv, 134, 93
Fukazawa, Y., Nakazawa, K., Isobe, N. et al. 2001, ApJ, 546, L87
Fusco-Femiano, R., Dal Fiume, D., Feretti, L. et al. 1999, ApJ, 513, L21
Fusco-Femiano, R., Orlandini, M., Brunetti, G. et al. 2004, ApJ, 602, L73
Gilfanov, M. R., Sunyaev, R. A., Churazov, E. M. 1987, Sov. Astron. Lett., 13, 233
Hansen, S. 2005, New Astronomy, 10, 371
Kaastra, J. S., Lieu, R., Mittaz, J. P. D. et al. 1999, ApJ, 519, L119
Kaastra, J. S., Bykov, A. M., Werner, N. 2009, A&A, in press, astro-ph/0905.4802
Kempner, J. C., Sarazin, C. L. 2000, ApJ, 530, 282
Kitaguchi, T., Makishima, K., Nakazawa, K. et al. 2007, in Proc. of 'The Extreme Universe in the Suzaku era'
Leubner, M. P. 2004, ApJ, 604,469
Liang, H., Dogiel, V., Birkinshaw, M. 2002, MNRAS, 337, 567
Mazzotta, P., Mazzitelli, G., Colafrancesco, S.et al. 1998, A&AS, 133, 403
Mewe, R., Gronenschild, E. H. B. M. 1981, ApSS, 45, 11
Molendi, S., De Grandi, S., Guainazzi 2002, A&A, 392, 13
Nakazawa, K., Makishima, K., Fukazawa, Y. 2007, PASJ, 59, 167
Owocki, S. P., Scudder, J. D. 1983, ApJ, 270, 758
Petrosian, V. 2001, ApJ, 557, 560
Petrosian, V., Bykov, A. M., Rephaeli, Y. 2008, SSRv, 134, 191
Petrosian, V., East, W. 2008, ApJ, 682, 175
Porquet, D., Arnaud, M., Decourchelle, A. 2001, A&A, 373, 1110
Prokhorov, D. A., Durret, F., Dogiel, V. A., Colafrancesco, S. 2009, A&A, 496, 25
Rephaeli, Y., Nevalainen, J., Ohashi, T., Bykov, A. M. 2008, SSRv, 134, 71
Rossetti, S., Molendi, S. 2004, A&A, 414, 41
Sarazin, C. L. 1986, Rev. Mod. Phys., 58, 1
Sarazin, C. L., Lieu, R. 1998, ApJ, 494, L177
Sarazin, C. L., Kempner, J. C. 2000, ApJ, 533, 73
Shimon, M., Rephaeli, Y. 2002, ApJ, 575, 12
Silva, R., Plastino, A. R., Lima, J. A. S. 1998, Physics Letters A, 249, 401
Tokoi, K., Sato, K., Ishisaki, Y. et al. 2008, PASJ, 60, 317
Tsallis, C. 1988, J. Stat. Phys., 52, 479
Tsallis, C. 1999, BrJPh, 29, 1
Verner, D. A., Ferland, G. J. 1996, ApJS, 103, 467
Werner, N., Durret, F., Ohashi, T. et al. 2008, Space Sci. Rev., 134, 337
Wik, D. R., Sarazin, C. L., Finoguenov, A. et al. 2009, ApJ, 696, 1700
Wolfe, B., Melia, F. 2006, ApJ, 638, 125
Wolfe, B., Melia, F. 2008, ApJ, 675, 156
Zel'dovich, Ya. B., Sunyaev, R. A. 1969, Ap&SS, 4, 285

Appendix A: Oxygen abundance drop in the solar corona

Often the particle distribution functions in space plasmas, e.g. solar corona plasma, are observed to be quasi-Maxwellian at the mean thermal energies, while they have non-Maxwellian supra-thermal tails at higher energies (e.g. Porquet et al. 2001). A Kappa-distribution is very convenient to model these particle distribution functions, since it fits both the thermal and supra-thermal parts of the observed energy spectra (for a review, see Leubner 2004).

The ionization and excitation rates for elements C, O, Fe for a Kappa-distribution of electrons in the solar corona were studied by Owocki & Scudder (1983) and Dzifcakova & Kulinova (2001, 2003).

We now demonstrate how the oxygen abundance inferred from X-ray observations yields important constraints on the fraction of high energy electron populations. For this purpose, a plasma with temperature $kT = 0.1$ keV (as in the solar corona) and an electron distribution function $f_2(x)$ are considered. The dependence of the ratio $A(O)$ of the oxygen abundances for a modified Maxwellian distribution and for a Maxwellian distribution on the fraction of high energy subrelativistic electrons is shown in Fig. A.1. Due to the impact of high energy subrelativistic electrons, the oxygen abundance estimate in the solar corona significantly decreases. Even if the fraction of high energy electrons is only 1% the drop of the oxygen abundance is about 30%.

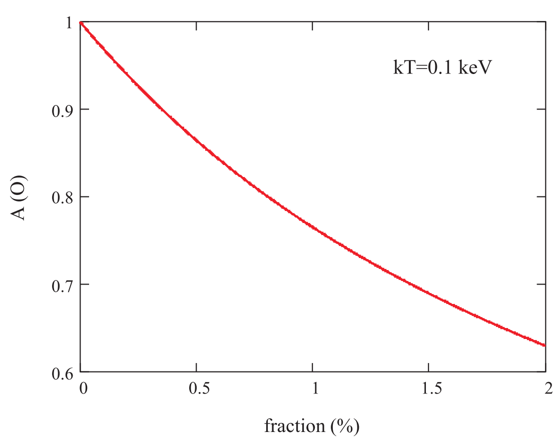

Fig. A.1. Dependence of the ratio of the oxygen abundances for a modified Maxwellian distribution and for a Maxwellian distribution on the fraction of high energy electrons.